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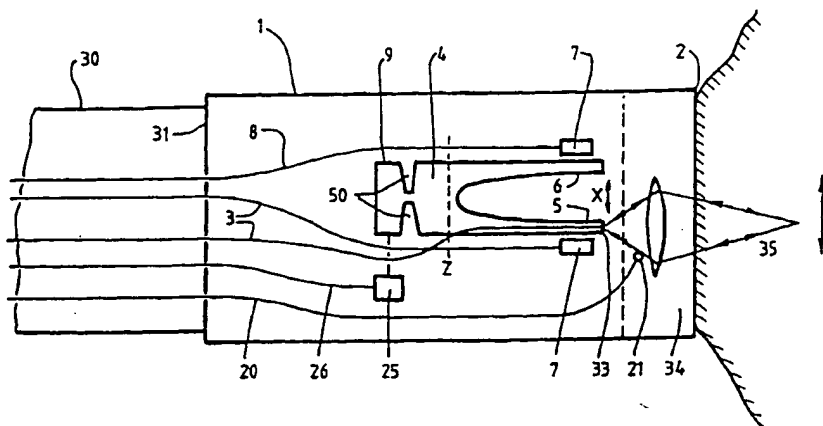
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(71) Applicant (for all designated States except US): OPTISCAN PTY. LTD. [AU/AU]; 27 Normanby Road, Notting Hill, VIC 3168 (AU).			
(72) Inventor; and			
(75) Inventor/Applicant (for US only): HARRIS, Martin, Russell [AU/AU]; Optiscan Pty. Ltd., 27 Normanby Road, Notting Hill, VIC 3168 (AU).		Published With international search report.	
(74) Agent: GRIFFITH HACK; 509 St. Kilda Road, Melbourne, VIC 3004 (AU).			

(54) Title: SCANNING MICROSCOPE WITH MINIATURE HEAD



(57) Abstract

The present invention provides a scanning microscope including: (1) a light source for supply of a light beam; (2) optical transmission means for transmitting the light beam from an entry end thereof proximate the light source to an exit end thereof proximate light focusing means, the light focusing means focusing the light emerging from the exit end to illuminate a point observation field on or within an object to be examined; (3) a detector to detect object emanated light emerging from the point observation field; (4) a scanner mounted in an optical head casing with the light focusing means, to cause the illuminated point observation field to scan over a two-dimensional cross section of the object such that an image of the object emanated light received by the detector over the cross section may be constructed; wherein the scanner includes counterbalancing elements to balance reactive forces caused by operation of the scanner, such that vibration of the light focusing means caused by coupling of the reactive forces to the light focusing means is reduced.

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SCANNING MICROSCOPE WITH MINIATURE HEAD

This invention relates to scanning microscope requiring
5 miniature optical heads, in particular but not limited to
laser scanning microscopes with miniature heads which can
utilised as an endoscope.

In order to construct a scanning microscope which has an
10 optical head small enough to be inserted in the body to
act as an endoscope, whereby internal organs of the body
may be inspected at a microscopic level, the optical head
of the scanning microscope must be able to be located
physically independently of the bulky light source and
15 photo-multiplier tube, and also must be miniaturised.

U.S. patents 5,120,953 and 5,161,053 ("Harris" and
"Dabbs" respectively) describe how a confocal microscope
may be constructed using optical fibres to make the
20 optical head geometrically independent from the light
source and/or detector. Harris and Dabbs further
disclose how a single fibre may be used to construct a
microscope where the exit end of the fibre acts as both
the source pinhole and return pinhole in a confocal
25 microscope.

Harris also describes embodiments where the fibre tip is
vibrated to produce a miniature optical head suitable for
an endoscope application. One practical problem with
30 such a design is that the scanning accuracy of the system
is limited by kinetic energy transfer to (and losses
from) the vibrating components of the scanning mechanism.

An alternative endoscope design remotely locates the scanning apparatus, and transmits the light down a standard endoscopic optical fibre bundle. This can be implemented by positioning the imaging end of the fibre bundle at the microscope stage of a laser scanning confocal microscope, or by using special optical arrangements as described in US Patent 5,323,009. This results at the specimen end of the fibre bundle in a corresponding scanning of the illuminating spot. A disadvantage with such systems is that the optical resolution is limited by the discrete nature of the fibre cores in the endoscopic bundle.

It is an object of the current invention to provide a miniaturised optical head for a scanning microscope having improved theoretical maximum resolution and reduced vibrational effects.

Therefore in accordance with a broad aspect of the invention there is provided a scanning microscope comprising

- (1) a light source for supply of a light beam;
- (2) optical transmission means for transmitting the light beam from an entry end thereof proximate the light source to an exit end thereof proximate light focusing means, the light focusing means focusing the light emerging from the exit end to illuminate a point observational field on or within an object to be examined;
- (3) a detector to detect object emanated light emerging from the point observational field;
- (4) a scanner mounted in an optical head casing with the light focusing means, to cause the illuminated point observational field to scan over a two-

dimensional cross-section of the object such that an image of the object emanated light received by the detector over the cross section may be constructed;

wherein the scanner comprises counterbalancing elements to balance reactive forces caused by operation of the scanner, such that vibration of the light focusing means caused by coupling of the reactive forces to the light focusing means is reduced.

10 Preferably, the scanner scans the point observational field in a raster fashion, the scanner having a fast scanner to scan over rows and a slow scanner operating in a transverse direction to the fast scanner to displace consecutive rows. The counterbalancing elements may
15 balance the reactive forces associated with the fast scan.

Preferably, the scanner and the counterbalancing element form a resonant system having a Q value sufficiently high
20 to enable low energy input requirements. Preferably too, the Q value is sufficiently low so that perturbations introduced by physical shock do not persist.

Preferably, the microscope comprises a fork with first
25 and second tines, the tines being caused to vibrate by driving means in mutually opposite phases, the vibration of the first and second tines providing the fast scanner and the counterbalancing element. The exit end of the optical transmission means may be fixed to the first tine
30 so as to follow the vibration of the first tine to provide the fast scanner. Alternatively, a mirror or mirrors may be fixed to the tines or one of the tines in the optical path of the light beam to provide the fast scanner. The tuning fork may be mounted to the optical

~~head casing with a flexible compliant material to further~~
reduce transfer of vibration to the optical head case.
The optical transmission means may comprise an optical
fibre, and the exit end of the optical transmission means
5 may be the exit end of the core of the optical fibre.
The fibre may have a core/cladding composition chosen to
have an effective numerical aperture as high as possible
and preferably greater than the nominal numerical
aperture of 0.12 of current standard fibres. The slow
-10- ~~scanner may be provided by movement of the tuning fork in~~
a direction perpendicular to the fast scan vibration,
such as by rotation of the tuning fork about an axis.

The microscope may be a confocal microscope. In this
15 case, the optical transmission means may include an
optical fibre (which may be single mode) and the object
emanated light returning from the illuminated point
observational field may return through the focusing means
and enter the exit end of the optical fibre, being
20 extracted from the optical fibre by confocal return light
separator means. The confocal return light separator
means may be an optical fibre coupler or a beam splitter.
Additionally, as described in International Application
PCT/AU96/00159, the optical transmission means may
25 include near confocal transmission means having a light
collection end adjacent the exit end of the confocal
transmission means to selectably collect light emanating
from regions close to the point observational field. The
near confocal transmission means may be provided by the
30 cladding of the single mode optical fibre.

Alternatively, the microscope may be non-confocal. In
this case, at least a portion of the object emanated
light emanating from the point observational field may be

~~collected and returned via means other than the exit end~~
of the optical transmission means. Such a non-confocal
microscope may be adapted to two-photon microscopy.

- 5 Preferably, the movement of the slow scanner is damped to
reduce coupling of vibration from the fast scanner or
from mechanical perturbations to the head.

- Preferably, the slow scanner may function by contraction
10 ~~and elongation of a wire whose dimensions are controlled~~
by temperature variation caused by a varying electrical
control current through the wire. Alternatively, the
slow scanner may function by a hydraulic actuator
mechanism connected by a fluid conducting tube to a
15 hydraulic driver pump remotely located which pumps fluid
into and out of the hydraulic actuator in the optical
head case.

- The driving means of the fast scanner may comprise a
20 first electromagnet proximate the first tine and a second
electromagnet proximate the second tine, the first and
second electromagnets being driven by alternating
currents of opposite phase. Energy to maintain the
driving means may be delivered to the scanner head by
25 means current-carrying wires or by pulses of
electromagnetic radiation conveyed by an optic wave
guide. The electromagnetic radiation may be laser pulses
conveyed by an optical fibre impinging on a photocell in
the head case which supplies current obtained by
30 conversion of the light energy the electromagnets.

A region of the optical fibre proximate the exit end
thereof may be manufactured with a reduced cladding
diameter to minimise inertia of the first tine in

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embodiments where the fibre is mounted on the first tine. Alternatively, the inertia may be reduced by hydrofluoric acid etching of the region of the fibre proximate the exit end.

5

Other preferred features of the invention will be apparent from the following description of preferred embodiments, where :

10 ~~Figure 1 shows an optical head constructed in accordance with a preferred embodiment of the current invention.~~

Referring now to Figure 1 there is shown an optical head case 1 providing an endoscope head shown in juxtaposition
15 to tissue 2 for in vivo observation. Optical transmission means 3 in the form of a single mode optical fibre passes down flexible endoscope tube 30 from a remotely located laser light source, detector and electronics. The remotely located component may be
20 constructed in accordance with the single fibre embodiments described in US Patent 5,120,953 by Harris and need not be repeated here.

The single mode optical fibre passes through a rear wall
25 31 of the optical head case 1 and an exit end 33 of the optical transmission means 3 is attached to a first tine 5 of a tuning fork 4. The tuning fork 4 has slots 50 in each side to reduce transfer of higher mode vibrations from the tines to the mounting portion 9. The tuning
30 fork 4 is driven by electromagnets 7 so that the first tine 5 and second tine 6 have mutually opposite vibration at a frequency of approximately 1000 Hz. The tines are machined to have as closely matching vibrational states

as possible, preferably compensating for any extra
inertia introduced by the optical transmission means 3.

The Q value of the vibration should be sufficiently high
5 to allow low energy impulse to the electromagnet 7 but
sufficiently low to damp transients caused by physical
shocks to the case. The optimal Q value can be
determined within these constraints by trial and error.
The electromagnets 7 are supplied by sinusoidal or pulsed
10 current through current of opposite phase carrying wires
8. The vibrations of the ends of the tines 5 and 6 have
an amplitude less than 1mm. A portion of the laser light
emerging from the fibre tip at the end of the vibrating
tine may be used to provide positional feedback by
15 impinging on an optic fibre 20, the tip of which contains
a fluorescent material 21 and which partly occludes the
laser beam at one side of the emergent cone of light as
it scans the lens. The returning fluorescence light
passes to a detector at the remote end (not shown), which
20 converts the magnitude of the light signal into an
electrical signal. The level of the electrical signal is
functionally related to the amount of the fluorescence-
doped plastic lying within the cone of illumination, and
therefore provides positional feedback to assist in
25 control of the electromagnet 7 to standardise and control
the fast scan vibration.

Second tine 6 provides the counterbalancing element to
counterbalance the reactive forces of the vibration of
30 the first tine 5. Since additional elements are attached
to first tine 5, increasing the mass of that tine,
similar compensating masses can be positioned
appropriately on second tine 6 to ensure sufficient
matching of the counter-balancing with the reactive

forces of vibration of the first tine 5. Alternatively,
the first and second tines can be machined with the
additional elements in place.

- 5 The exit end 33 of the optical transmission means
projects a cone of illumination on to a light focusing
means 34 which focuses the illumination into a
diffraction-limited point observational field within the
tissue 2. The vibration in the fast scan direction shown
10 by arrow X of the first tine 5 is transformed into
scanning along a single row across of a two dimensional
area within tissue 2 along arrow Y.

- The tuning fork 4 is mounted onto the optical head case
15 by anti-vibration mounting means (not shown). This may
be interposed at the point of attachment 9 of the tuning
fork to the optical head case 1 or it may be integral
with the slots 50. The slow scan is provided by
reciprocating rotation about an axis Z, preferably
20 located so that the axis of slow scan rotation 2 and the
axis of fast scan vibration intersect. The rotation is
slow scanner 25, actuated by contraction and elongation
of "Nitinol" wire, controlled by a second current
carrying wire 25, through which a current is passed in a
25 varying level to provide the slow scan reciprocation.

- Further reduction in the inertia of the first tine may be
achieved by hydrofluoric acid etching of a portion of the
optical fibre 3 proximate the exit end, whereby a portion
30 of the cladding has been reduced in diameter to reduce
the inertia of the fibre.

Alternatively, the etching of the fibre may be in the
form of a gradual taper, which has an additional benefit

that the numerical aperture of the exit end of the fibre is thereby increased, allowing a reduction in the distance of the focusing optics 34 from the exit end 33.

- 5 It has been found that by providing a fast scan mechanism which has counterbalancing movements to balance the fast scan vibrations, transfer of vibrations to the optical head case 1 can be minimised, thereby improving the quality of the image produced.

10

- Modifications may be made to the invention as would be apparent to a person skilled in the art of scanning microscope design. For example, the scope of the invention is not limited to confocal arrangements, and
- 15 suitably miniaturised heads may be provided which make use of two photon fluorescence, which does not require a confocal return of illumination. Additionally, the cladding of the fibre 3 can be used to return near-confocal, as described in PCT/AU96/00159. However, in
- 20 this case, etching of the exit end of the fibre to reduce inertia may need to be performed so as to produce a step rather than a taper. The use of a specially produced fibre with reduced diameter cladding, of total glass diameter about 25 microns is also contemplated. Further
- 25 still, the provision of current-carrying wires 8 to drive electromagnets 7 may be avoided by the use of an optical wave guide in the place of the current-carrying wires, which projects light onto a photo detector within the head case 1 converting the light energy into electrical
- 30 energy to energise the electromagnet 7. The second current-carrying wire 26 may similarly may be replaced by a hydraulic connection to operate an alternate hydraulic slow scan mechanism. In this manner, electrical

connections passing down the flexible endoscope tube 30
may be avoided.

These and other modifications may be made without
5 departing from the ambit of the current invention, the
nature of which can be ascertained from the foregoing
description and the drawing.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A scanning microscope including:
 - (1) a light source for supply of a light beam;
 - 5 (2) optical transmission means for transmitting the light beam from an entry end thereof proximate the light source to an exit end thereof proximate light focusing means, the light focusing means focusing the light emerging from the exit end to illuminate a point
 - 10 observation field on or within an object to be examined;
 - (3) a detector to detect object emanated light emerging from the point observation field;
 - (4) a scanner mounted in an optical head casing with the light focusing means, to cause the illuminated
 - 15 point observation field to scan over a two-dimensional cross-section of the object such that an image of the object emanated light received by the detector over the cross section may be constructed;
 - wherein the scanner includes counterbalancing
 - 20 elements to balance reactive forces caused by operation of the scanner, such that vibration of the light focusing means caused by coupling of the reactive forces to the light focusing means is reduced.
- 25 2. A scanning microscope as claimed in claim 1, wherein said scanner is operable to scan the point observational field in a raster fashion, the scanner having a fast scanner to scan over rows and a slow scanner operating in a transverse direction to the fast scanner to displace
- 30 consecutive rows.
3. A scanning microscope as claimed in claim 2, wherein said counterbalancing elements balance the reactive forces associated with the fast scanner.
- 35 4. A scanning microscope as claimed in any one of the preceding claims, wherein said scanner and said

counterbalancing elements form a resonant system having a Q value sufficiently high to enable low energy input requirements.

5 5. A scanning microscope as claimed in claim 5; wherein said Q value is sufficiently low so that perturbations introduced by physical shock do not persist.

6. A scanning microscope as claimed in either claim 2 or
10 3, wherein said microscope includes a fork with first and second tines, the tines being operable to vibrate by driving means in mutually opposite phases, the vibration of the first and second tines providing the fast scanner and the counterbalancing element.

15

7. A scanning microscope as claimed in claim 6, wherein said exit end of the optical transmission means is fixed to said first tine so as to follow the vibration of said first tine to provide said fast scanner.

20

8. A scanning microscope as claimed in claim 6, wherein said microscope includes a mirror or mirrors fixed either to said tines or to one of said tines in the optical path of the light beam to provide said fast scanner.

25

9. A scanning microscope as claimed in any one of claims 6 to 8, wherein said fork is mounted to the optical head casing with a flexible compliant material to further reduce transfer of vibration to the optical head case.

30

10. A scanning microscope as claimed in any one of the preceding claims, wherein said optical transmission means comprises an optical fibre, and the exit end of the optical transmission means forms the exit end of the core of the
35 optical fibre.

11. A scanning microscope as claimed in claim 10, wherein

said fibre has a core/cladding composition chosen to have an effective numerical aperture as high as possible.

12. A scanning microscope as claimed in claim 11, wherein
5 said effective numerical aperture is greater than the nominal numerical aperture of 0.12 of current standard fibres.

13. A scanning microscope as claimed in any one of claims
10 6 to 9, wherein said slow scanner is provided by movement of said fork in a direction perpendicular to the fast scan vibration.

14. A scanning microscope as claimed in claim 13, wherein
15 said movement is rotation of said fork about an axis.

15. A scanning microscope as claimed in any one of the preceding claims, wherein said microscope is a confocal microscope.
20

16. A scanning microscope as claimed in claim 15, wherein said optical transmission means includes an optical fibre.

17. A scanning microscope as claimed in either claim 15 or
25 16, arranged so that said object emanated light returning from the illuminated point observational field returns through said focusing means and enters said exit end of said optical fibre, being extracted from the optical fibre by confocal return light separator means.

18. A scanning microscope as claimed in claim 17, wherein
30 said confocal return light separator means is an optical fibre coupler or a beam splitter.

19. A scanning microscope as claimed in any one of the preceding claims, wherein said optical transmission means
35 includes near confocal transmission means having a light

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collection end adjacent to said exit end of said confocal transmission means to selectably collect light emanating from regions close to the point observational field.

- 5 20. A scanning microscope as claimed in claim 19, wherein said optical fibre is single moded and said near confocal transmission means is provided by the cladding of said single mode optical fibre.

- 10 ~~21. A scanning microscope as claimed in any one of claims 1 to 14, wherein said microscope is non-confocal.~~

- 15 22. A scanning microscope as claimed in claim 21, wherein said microscope is arranged so that at least a portion of said object emanated light emanating from the point observational field is collected and returned via means other than the exit end of the optical transmission means.

- 20 23. A scanning microscope as claimed in claim 22, wherein said microscope is adapted to two-photon microscopy.

- 25 24. A scanning microscope as claimed in either claim 2 or 3, wherein movement of said slow scanner is damped to reduce coupling of vibration from the fast scanner or from mechanical perturbations to the head.

- 30 25. A scanning microscope as claimed in either claim 2 or 3, wherein said slow scanner is operable to function by contraction and elongation of a wire whose dimensions are controlled by temperature variation caused by a varying electrical control current through the wire.

- 35 26. A scanning microscope as claimed in either claim 2 or 3, wherein said slow scanner is operable to function by a hydraulic actuator mechanism connected by a fluid conducting tube to a hydraulic driver pump remotely located which pumps fluid into and out of the hydraulic actuator in

the optical head case.

27. A scanning microscope as claimed in claim 6, wherein said driving means of the fast scanner includes a first
5 electromagnet proximate said first tine and a second electromagnet proximate said second tine, the first and second electromagnets being driven by alternating currents of opposite phase.

~~10 28. A scanning microscope as claimed in either claim 6 or 27, wherein energy to maintain the driving means is delivered to the scanner head by means of current-carrying wires or by pulses of electromagnetic radiation conveyed by an optic wave guide.~~

15 29. A scanning microscope as claimed in claim 28, wherein said electromagnetic radiation comprises laser pulses conveyed by an optical fibre impinging on a photocell in the head case which supplies current obtained by conversion
20 of the light energy the electromagnets.

30. A scanning microscope as claimed in claim 10, wherein a region of said optical fibre proximate the exit end is manufactured with a reduced cladding diameter to minimise
25 inertia of the first tine in embodiments where said fibre is mounted on or attached to said first tine.

31. A scanning microscope as claimed in claim 10, wherein inertia of said first tine is reduced by hydrofluoric acid
30 etching of a region of the fibre proximate the exit end.

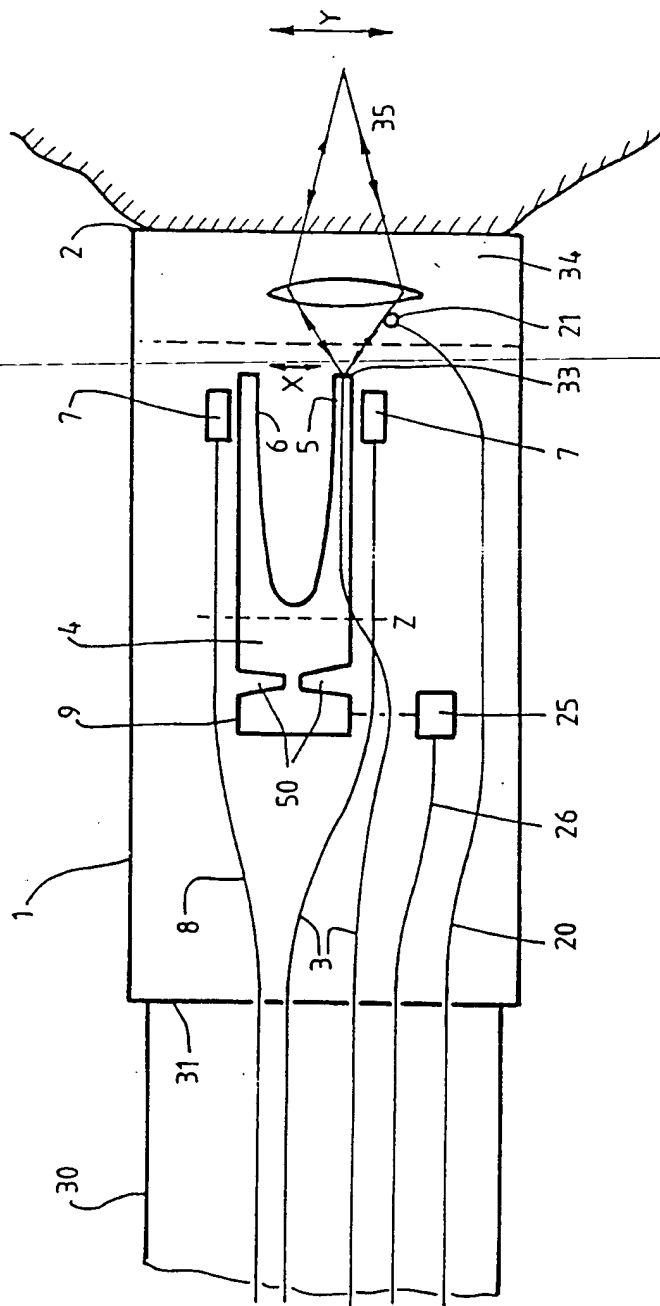


Fig. 1.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/AU 98/00561

A. CLASSIFICATION OF SUBJECT MATTER		
Int Cl ⁶ : G02B 21/00, 21/06, 21/18, 26/08, 26/10		
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B. FIELDS SEARCHED		
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched AU : IPC as above		
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C. DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X, Y	GB 2289759 A (KARRAIE) 29 November 1995 See whole document	1, 2, 6, 8, 10, 15, 16-19, 21, 23-25, 27-29
Y	Patent Abstracts of Japan, JP 5 - 127682 A (FUJI PHOTO FILM CO LTD) 25 May 1993 abstract; figure	1
Y	Patent Abstracts of Japan, JP 4 - 296811 A (FUJI PHOTO FILM CO LTD) 21 October 1992 abstract; figure	1
<input checked="" type="checkbox"/> Further documents are listed in the continuation of Box C <input checked="" type="checkbox"/> See patent family annex		
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Date of the actual completion of the international search 24 August 1998		Date of mailing of the international search report 28 AUG 1998
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C (Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Derwent Abstract Accession No. 97-376446, Class U11, JP 09159925 A (ISHIKA WAJIMA HARIMA HEAVY IND) 20 June 1997 abstract, figure	1
T	US 5788639 A (ZAVISLAN J and EASTMAN J) 4 August 1998 See whole document	1-31
A	AU 53303/94 A, 669760 B (MONASH UNIVERSITY) 24 May 1994 See whole document	1-31
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International Application No.
PCT/AU 98/00561

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Patent Document Cited in Search Report				Patent Family Member			
GB	2289759	CH	686906	DE	19510368	DE	29521543
		US	5641896				
AU	53303/94	AU	669760	US	5659642	WO	9410595
AU	49332/96	AU	694005	WO	9630796	DE	19681304
		CA	2215975				
END OF ANNEX							